J Nanostruct 16(4): 5737-5742, Autumn 2026

RESEARCH PAPER

Exploring Plasma parameters of CdO Via Laser-Induced Breakdown Spectroscopy

Basil Sabah Ahmed, Shatha Abdulla Taha, Taha N. Al-badrani, Othman Abed Fahad *

Ministry of Education, Direction of Education in AL-Anbar, Anbar, Iraq

ARTICLE INFO

Article History:
Received 17 June 2026
Accepted 22 September 2026
Published 01 October 2026

Keywords:
Boltzmann
Cadmium Spectroscopy
Cd Plasma
Electron temperature
LIBS

ABSTRACT

In this study, the physical properties of laser-generated plasma at different energies ranging from 200 to 500 mJ were analyzed. The results showed that the temperature of the electrons (Te) ranged between 0.632 and 0.653 eV, with a slight tendency to increase as the laser energy rises, demonstrating the increase in the electrons' kinetic energy within the plasma. A marked increase in electron density (ne) was also observed, increasing from 2.606 $\times 10^{18}$ to 3.909 $\times 10^{18}$ cm^{-3}, which was directly reflected on the plasma frequency (fp), which rose from 14.496 $\times 10^{12}$ to 17.754 $\times 10^{12}$ Hz, in line with the known relationship between plasma frequency and electron density. On the other hand, (λD) gradually decreased from 0.366 $\times 10^{-6}$ to 0.304 $\times 10^{-6}$ cm, indicating an increase in the effect of electrostatic fields within the plasma as a result of the increasing concentration of electrons. The number of Nd saw a slight decrease from 0.53 to 0.46, reflecting a change in the degree of plasma perfection as the laser energy rises. These results clearly show that increasing laser energy leads to the production of more intense plasma with complex dynamic properties, which helps us better understand plasma behavior under various spectral and thermal effects.

How to cite this article
Ahmed B., Abdulla Taha S., Al-badrani T., Fahad O. Exploring Plasma parameters of CdO Via Laser-Induced Breakdown Spectroscopy. J Nanostruct, 2026; 16(4):5737-5742. DOI: 10.22052/JNS.2026.04.102

INTRODUCTION

Laser-induced plasmas of varying energies have been of interest to both theoretical and experimental research since the development of high-power lasers. This plasma is emitted by focusing a laser beam onto the surface of the excited material, followed by evaporation, producing extremely dense and extremely hot plasma. Due to the varying density of the plasma, energy can be transferred via radiation or shock waves [1].

The identification of several possibilities for the transmission of spectral lines is a broad field of scientific research because of its high importance in many research in laser physics, plasma physics, as well as atomic structure physics, and its astronomical applications [2]. Requires accuracy in the search of physical spectra to provide accurate atomic data in a wide range [3].

Because plasma is a medium rich in charged particles and energy, and because cadmium is a good laboratory diagnostic element and is a heavy material with distinct emission lines across a wide spectrum, it is an ideal model for studying the properties of laser-generated plasma [4]. By using spectroscopy (LIBS), which examines emission lines based on Stark models and Boltzmann, we may evaluate plasma components and determine

* *Corresponding Author Email: othmanabad2@gmail.com*

This work is licensed under the Creative Commons Attribution 4.0 International License.
To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

(Te) and (ne) [5]. After reviewing numerous published studies, we find that the cadmium plasma spectrum has a spectral response that combines several variables, including pressure, gas type, and laser power. These parameters help us better understand plasma dynamics and how they change over time, In light of this information on spectral response in previously published scientific research, researchers have developed a method to improve the accuracy of plasma diagnostics as well as increase the effectiveness of technology applications through in-depth study of the results of spectral responses [6]. The reason for using methods such as polarized or laboratory-limited LIBS is that it can reduce RSD and increase the stability and sensitivity of cadmium spectral signal detection, especially in environmental and industrial applications [7]. In addition, cadmium plasma spectroscopy is used to track heavy metal residues, whether these pollutants are in water or soil, and to identify the pollutants. This enhances the spectroscopy's potential as a highly effective and environmentally friendly method [8]. Cd plasma spectroscopy is also used to detect the amount of materials in the electronics industry, such as solder in printed circuits, and in forensics to identify cadmium deposits in biological tissue [9]. Developing physical models to understand energy transfer, ionization, and ion-electron interactions under thermal no equilibrium conditions is crucial to the study of cadmium plasmas. These theoretical results improve our understanding of plasma properties in both high and low energy ranges [10]. The resulting cadmium plasma spectrum contains electrons, atoms, and ions when a short laser pulse at various laser energies (such as a 1064 W Nd:YAG laser) excites a cadmium-containing surface for elemental analysis. The Stark equation can be used to calculate the spectral line amplitudes, and the Boltzmann model can be used to study the energy distribution and determine the electron temperature and density.

The purpose of studying the spectrum of Cd plasma is to determine its atomic structure, improve the conditions of its formation process, and employ these results in several practical applications, whether analytical or technical.

MATERIALS AND METHODS

A Q-switched pulsed Nd:YAG laser was used to generate the plasma for the experiment testing the Cd target. Increasing the distance between the laser lens and the target can change the diameter of the laser spot. The pulse duration is 9 ns, with a frequency of 6 Hz and a wavelength of 1064 nm, which is the precise distance required for the instrument's accuracy and precision during measurements. The lens's focal length is 10 cm. The results were analyzed and compared with the database of the National Institute of Standards and Technology (NIST) [11]. Although a short focal length lens has a limited depth of focus, it can be employed for improved splitting and small beam diameters. Diagrams of LIBS are shown in Fig. 1.

RESULTS AND DISCUSSION

The emission spectra of sample Cd employing varying laser energy (from 200 to 500 mJ) with a 3.0 s time delay are shown in Fig. 2. The optical cable and the plasma were separated by 15 mm. The graphic shows that when the laser's energy increases, the emission lines' intensity increases noticeably, suggesting that the plasma's density and the number of atoms or ions in the sample have increased. Several distinctive spectral lines have been identified for neutral cadmium atoms (Cd I) as well as single ions (Cd II), as shown by colored vertical lines. The spectrum extends within the range from 200 to 900 nm, which includes both the ultraviolet and visible bands, and sharp and distinctive peaks appear at wavelengths such as 361.05 nm, 467.81 nm, and 643.85 nm, which correspond to the reference values known to cadmium spectrum. These results reflect the effectiveness of LIBS technology in the qualitative and quantitative detection of elements, and enhance its importance in the analysis of materials in a non-destructive and rapid manner. Region using NIST database and reference [12] .As laser energy increases, at 500 mJ, the cd I line at exhibits intensity four times higher than at 200 mJ, indicating increased ablation and ionization.

Fig. 3 shows how the electron temperatures (Te) of the best linear fit slope were constrained by the Boltzmann plot. The ionization process itself and a conflict of the same atomic form are both part of Boltzmann's plan. We note from the figure that increasing the energy of the laser leads to an overheating of electrons, which is useful in the design and analysis of plasma applications such as coating, spectroscopy, or nanosynufacturing.

Fig. 4 collisions with charged particles cause the plasma spectral lines to expand and change their peak wavelength, resulting in high extension.

CC BY

Four distinct laser energy values 200, 300, 400, and 500 mJ were used to measure the spectral line's intensity, as seen in the image. The findings demonstrated a definite positive correlation between the laser energy and the spectral signal's intensity, with the intensity rising noticeably as the laser energy rose. This was indicative of improved ionization efficiency and the creation of hotter, denser plasma. The spectral line was installed using the Lorentzian function, which showed good compatibility with the shape of the peak, suggesting that the spectral expansion is often caused by pressure effects or collisions within the plasma. It also appears that the peak position remained almost constant at 441.56 nm at different laser energies, demonstrating the stability of the spectral shift of Cd II regardless of the changes in the laser energies used [13,

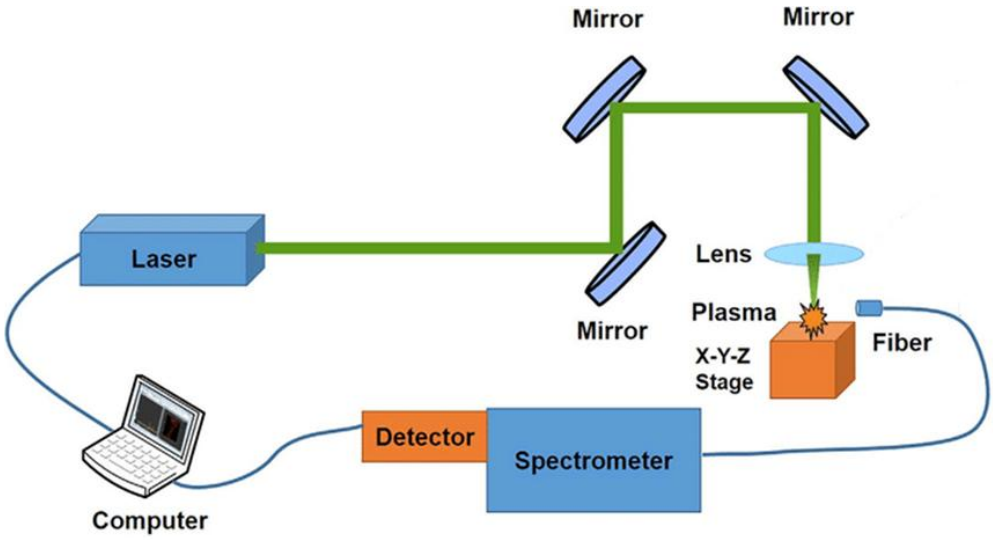


Fig. 1. Diagrams of LIBS.

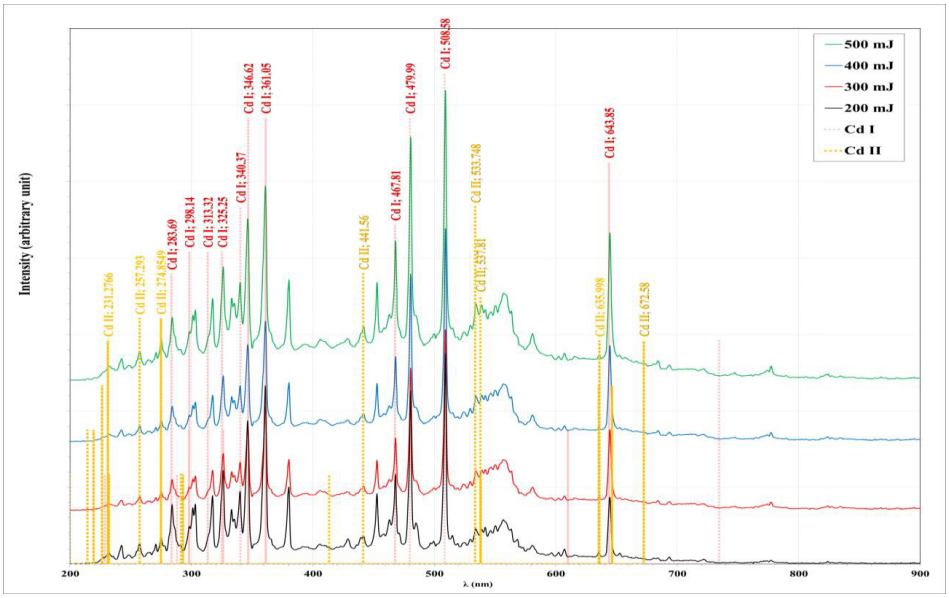


Fig. 2. Plasma emission spectroscopy patterns from a Cd target at varying laser energies.

CC BY

14]. Based on the results, it is important to vary the laser energies to achieve the lowest emission intensity without endangering the sample or distorting the spectral signal. These results also provide a crucial reference for future research to study the behavior of cadmium spectra around element concentrations and plasma behavior under various conditions [15,16].

Te and Ne laser power density differences are seen in Fig. 5. The electron density clearly increases with increasing pressure, as seen by the red curve, which goes from roughly 2.5 × 10

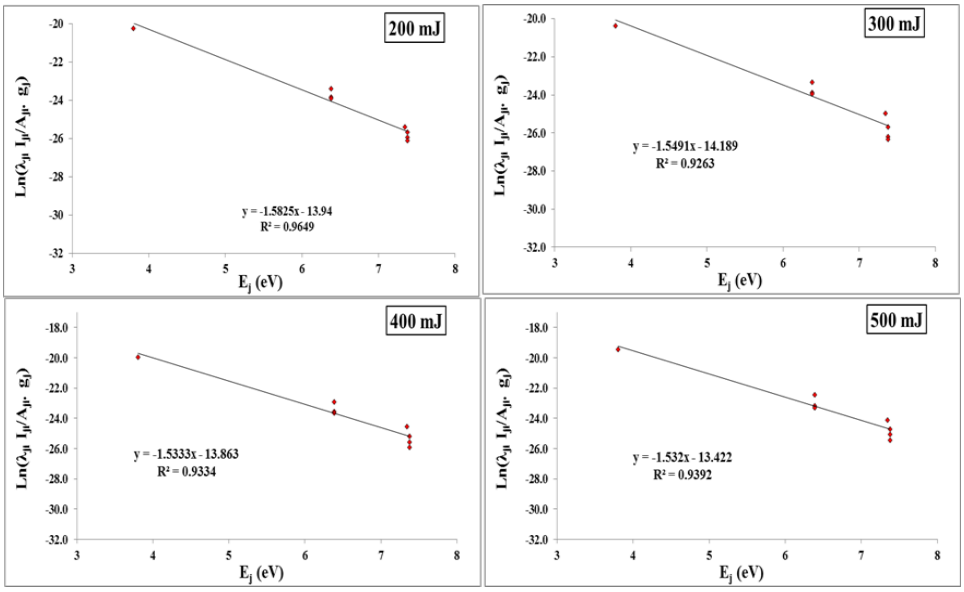


Fig. 3. Shows the plasma emission Boltzmann plat for a Cd target at various laser energy.

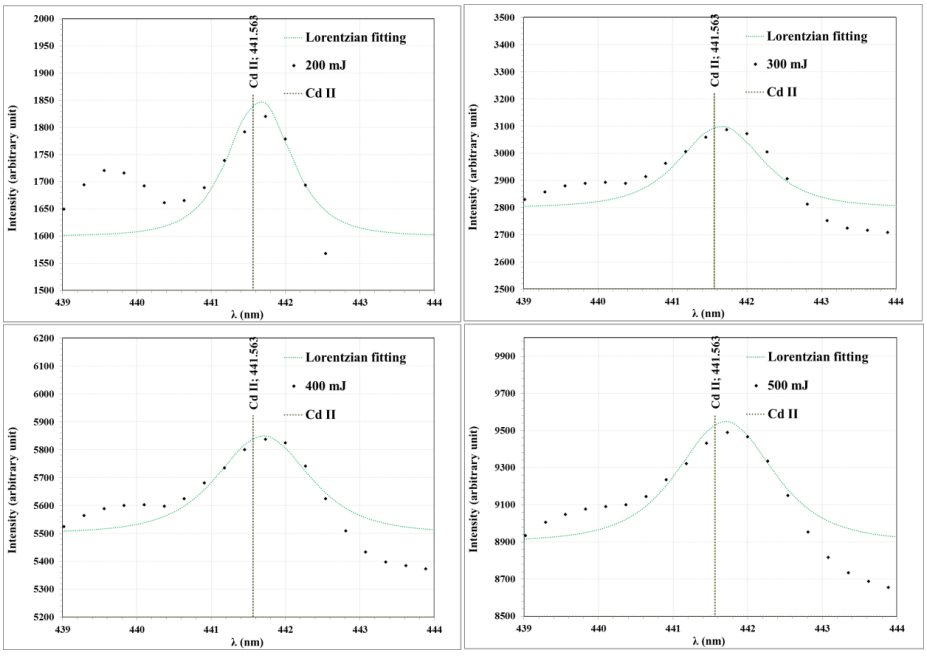


Fig. 4. Stark broadening for 441.56 nm Cd II line.

CC BY

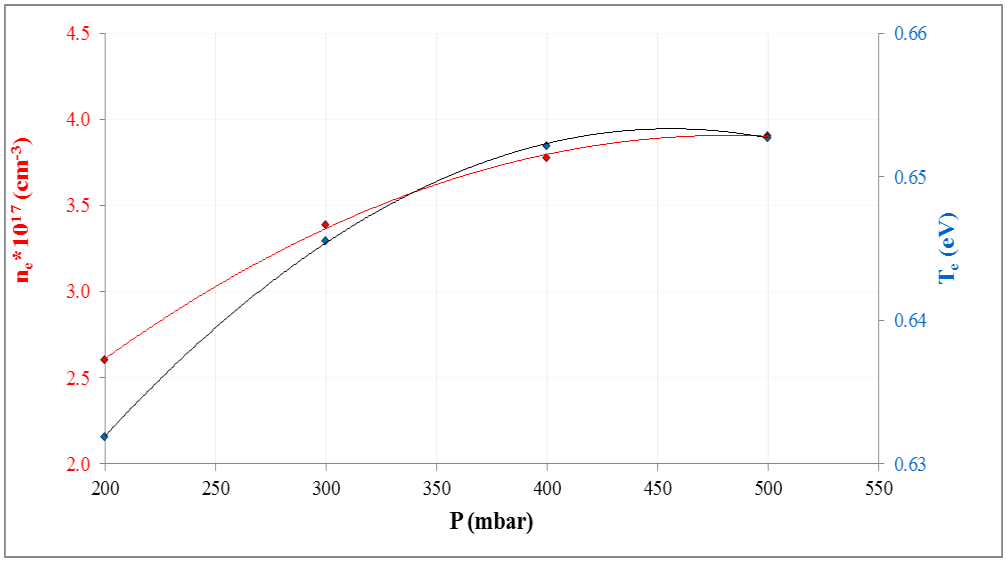


Fig. 5. Clarification of T_e and n_e versus the laser energy.

Table 1. Cd plasma parameters under varying laser energies.

E (mJ)	T_e (eV)	$n_e \times 10^{18}$ (cm^{-3})	f_p (Hz) $\times 10^{12}$	$\lambda_D \times 10^{-6}$(cm)	N_d
200	0.632	2.606	14.496	0.366	0.53
300	0.646	3.388	16.528	0.324	0.48
400	0.652	3.779	17.456	0.309	0.47
500	0.653	3.909	17.754	0.304	0.46

^{17} cm^{-1} at 200 to roughly 3.9 × 10 ^{17} cm^{-1} at 500. This phenomenon results from an increase in the number of gas particles in the plasma chamber, which raises the ionization rate by raising the rate at which electrons and neutral molecules collide. On the other hand, the black curve shows that the temperature of Te electrons increases only slightly with pressure, ranging between 0.635 eV and 0.655 eV, before tending to stabilize at higher pressures. This behavior is explained by the fact that frequent collisions at high pressures lead to the electrons losing part of their energy, which limits the increase in their temperature despite the high ionization rate[17]. These results indicate that laser energy control is an effective tool for adjusting plasma properties, especially if the goal is to increase electron density without causing excessive temperature rise, which is desirable in applications such as thin layer deposition or fine surface treatment.

CONCLUSION

Significantly, the intensity of the induced plasma spectrum lines of different laser cards depends on several conditions, including the surrounding environmental conditions. Where the contact of the laser beam with the metal target is one of the effective means of producing plasma columns consisting of neutral molecules, ions and electrons. With the increase of laser energy, the decrease in λ_D and N_d also appear with a rise in f_p and the number of electrons and a slight variation in electron temperature that reaches stability, as the laser energy significantly affects the plasma parameters with the increase in laser energies. Findings directly apply to LIBS optimization for Cd detection in environmental pollutants or CdO thin-film quality control.

CC BY

ACKNOWLEDGEMENTS

The plasma laboratory at the College of Science, University of Baghdad.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCES

1. Marzoughi M, Babaee O, Mohajerzadeh S. Plasma-driven formation of vertically aligned silver–phosphorus core–shell nanostructures. Sci Rep. 2026;16(1).
2. Stoffels E, Kieft IE, Sladek REJ, van der Laan EP, Bronneberg D, Broers JLV. Plasma interactions with living cells. The 31st IEEE International Conference on Plasma Science, 2004. ICOPS 2004. IEEE Conference Record - Abstracts.: IEEE. p. 114-114.
3. Slimani Y, Ünal B, Baykal A, Thakur A. Crystal structure, morphology, magnetic, electrical, and dielectric characterization of amphoteric Yb_2O_3-modified lead-free BaTiO3 perovskite. Micro and Nanostructures. 2026;216:208709.
4. Butcher DJ. Recent developments in graphite furnace atomic absorption spectrometry. Advances in Atomic Spectroscopy: Elsevier; 1998. p. 151-175.
5. Yao M, Wan Q, Liu M, Wang X, Xu J. Use of spectral transmittance model to improve the detection accuracy of chromium in soil. Appl Opt. 2024;63(32):8442.
6. Zhao H-L, Cai L-L, Wu G. On polarization resolved laser induced breakdown spectroscopy combined with support-vector regression to improve the accuracy of soil heavy-metal (Cd) detection. Chinese Journal of Analytical Chemistry. 2023;51(2):100176.
7. Bolea-Fernandez E, Clough R, Fisher A, Gibson B, Russell B. Atomic spectrometry update: review of advances in the analysis of metals, chemicals and materials. J Anal At Spectrom. 2024;39(11):2617-2693.
8. Noll R. Laser-Induced Breakdown Spectroscopy. Laser-Induced Breakdown Spectroscopy: Springer Berlin Heidelberg; 2011. p. 7-15.
9. Goncharova I, Guichaoua D, Taboukhat S, Tarbi A, Chtouki T, Erguig H, et al. Laser-induced breakdown spectroscopy application for heavy metals detection in water: A review. Spectrochimica Acta Part B: Atomic Spectroscopy. 2024;217:106943.
10. Ali HA, Turki II, Al-Obaidy GS, Rzaij JM. Evaluating the Gamma-Ray Attenuation Characteristics of Various Radioactive Sources Using Binary and Ternary Polymer Blends. Revue des composites et des matériaux avancés. 2025;35(5).
11. Werner WSM, Powell CJ. Applications of the National Institute of Standards and Technology (NIST) database for the simulation of electron spectra for surface analysis for quantitative x-ray photoelectron spectroscopy of nanostructures. Journal of Vacuum Science and Technology A: Vacuum, Surfaces, and Films. 2021;39(6).
12. Fahad OA, Mohammed AS, Salih EY, Mohammed MKA. Perpendicular sheet-like alignment of a self-driven MoS_2 /Si heterostructure for Vis-NIR wavelength detection. Nanoscale. 2025;17(30):17795-17802.
13. Gondal MA, Hussain T, Yamani ZH, Baig MA. On-line monitoring of remediation process of chromium polluted soil using LIBS. J Hazard Mater. 2009;163(2-3):1265-1271.
14. Harilal SS, O'Shay B, Tillack MS, Mathew MV. Spectroscopic characterization of laser-induced tin plasma. J Appl Phys. 2005;98(1).
15. Noll R. Laser-Induced Breakdown Spectroscopy. Laser-Induced Breakdown Spectroscopy: Springer Nature Switzerland; 2026. p. 15-27.
16. Laser-Induced Breakdown Spectroscopy (LIBS): Cambridge University Press; 2006.
17. Dual-Route Preparation of Fe_2O_3 Nanostructures (Green and PLD) for Superior H_2S Detection Sensitivity. Journal of Ovonic Research. 2026;22(2).

CC BY